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Evaluation of color traps for monitoring *Lygus* spp.: Design, placement, height, time of day, and non-target effects☆

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Abstract

Lygus hesperus and *Lygus lineolaris* are two of the most economically important plant bugs in North America. Here we present results from field trials that evaluated effective trap characteristics for maximizing *Lygus* spp. and other herbivorous insect capture, while minimizing beneficial insect capture. The response of lygus bugs, several other key herbivore species and predators to hue (white, clear, black, yellow, orange, blue, purple, green and red) and value (black, white and two neutral grays) was examined in alfalfa over three seasons using traps coated with Pestick adhesive. *Lygus* spp. exhibited a broad response to trap hue, but showed no response to trap value. Additionally, we showed that time of day, trap height and trap placement influenced the number of *Lygus* spp. captured. More *Lygus* spp. were trapped from late afternoon to dusk compared to all other times of the day, and more males than females were captured on sticky traps even though the sexes were at parity in field sweep net samples. In the alfalfa setting, male lygus were more likely to be captured on traps placed 20 cm above the ground; traps placed 50 and 100 cm above the ground caught similar numbers of males and females. The highest number of plant bugs was captured when traps were placed in a cleared area between two alfalfa fields; lower numbers were captured on traps at the edge and in the center of the field. All other herbivores exhibited distinct preferences to trap hue and, in some cases, trap value. Predators were rarely trapped, but did exhibit preferences to trap color (i.e., hue and value) characteristics. The potential of using sticky traps with specific hue and value characteristics to monitor *Lygus* spp. effectively is discussed.
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Keywords: Western tarnished plant bug; Visual cues; Alfalfa; Sticky traps; Natural enemies; Spectroradiometer

1. Introduction

In the southwestern United States, the western tarnished plant bug, *Lygus hesperus* Knight, is a serious economic pest. In Arizona, it is ranked as one of the most important pests in cotton (Ellsworth and Barkley, 2001). Before the widespread use of Bt (*Bacillus thuringiensis*) cotton, this insect occasionally caused significant damage. However, as the area planted in Bt cotton increased, the number of broad-spectrum insecticide applications decreased, which previously helped suppress populations of *L. hesperus* (Barkley and Ellsworth, 2004). Since the mid-1990s, the proportion of insecticide applications directed at lygus bugs has increased substantially (Ellsworth and Jones, 2001).

Although conventional pesticides are still effective in controlling this insect, repeated use often leads to resistance and disruption of the natural enemy complex. Environmentally sound control options are limited and a long search for the sex pheromone of this species, and the closely related *Lygus lineolaris* (Palisot de Beauvois), has proven disappointing as field trials failed to attract males in adequate numbers (Gueldner and Parrott, 1978; Hedin et al., 1985; Aldrich et al., 1988; McLaughlin, 1998; Ho and Millar, 2002).

We have taken a complementary approach that involves identifying pertinent host-plant cues that might be used for monitoring and/or mass trapping *Lygus* spp. Detection of

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host plants by phytophagous insects often involves visual recognition. This recognition may include responses to color, size, shape or silhouettes (Prokopy and Owens, 1983).

In designing a trap for monitoring or mass trapping insect pests, it is often important that these visual variables be considered. Traps based on color characteristics have been used extensively in the field and greenhouse for a variety of pests (Moffitt, 1964; Kirk, 1984; Brødsgaard, 1989; Gillespie and Vernon, 1990; Matteson and Terry, 1992; Teulon et al., 1999; Blackmer et al., 2004a, 2006; Demirel and Cranshaw, 2006). The advantages of traps that employ visual cues are that their presence is instantaneously established, they function independently of air movement, and they are generally effective from a distance and from any direction, provided there are no obstacles between the trap and the insect (Miller and Strickler, 1984).

Previous studies with plant bugs have demonstrated attraction to various colors, but the response appears to be species specific and, in some cases, habitat dependent. Landis and Fox (1972) examined the response of *L. hesperus* and *Lygus elisus* Van Duzee to colored water-pan traps and found that significantly more *Lygus* spp. were trapped in light orange-yellow and deep chrome-yellow pans than in green, red or pink water traps. For *L. lineolaris*, Prokopy et al. (1979) found that non-UV-reflecting gloss white, zinc (Zn) white, Zoecon yellow and clear Plexiglas rectangles captured equivalent numbers of adults, but significantly greater numbers than other hues of yellow, green, orange, blue, red, aluminum foil, black and lead (Pb)-white rectangles. In peach orchards, Legrand and Los (2003) found that *L. lineolaris* was captured in higher numbers on pink sticky traps than on white traps. The pink trap closely mimicked the color of peach flower petals; however, most insects were trapped after peach petals were gone. Clearly, there is a lot of variation in response in the group and each monitoring scheme may require independent verification of trap design and color.

A few studies have examined the effects of trap design (Prokopy et al., 1979; Villavaso, 2004), height (Prokopy et al., 1979; Boivin and Stewart, 1984; Rancourt et al., 2000), placement (Boivin et al., 1982), time of day (Rancourt et al., 2000) and time of year (Boivin et al., 1982) for *L. lineolaris*. None of these parameters have been examined with sticky traps for *L. hesperus*. Landis and Fox (1972) examined the late autumn and early spring movement of *L. hesperus* using a yellow mechanical trap, and Butler (1972) examined their movement relative to the time of day using a truck-mounted net. Knowledge of how these various trap characteristics impact lygus bug capture will enhance our ability to monitor and/or mass trap these important economic pests.

Here we examined the response of *L. hesperus* and *L. lineolaris* to visual cues (trap hue = dominant wavelength and value = intensity over a range of wavelengths) in alfalfa, *Medicago sativa* L. (cv Mecca II). Concurrently, we monitored the response of additional key herbivores and predators. By examining the pest and beneficial complex in alfalfa, we hope to identify trap characteristics that will be selective. We also present results on the effect of time of day, trap height, trap placement and daily vs. weekly collection intervals on *Lygus* spp. capture.

2. Materials and methods

2.1. Trap design

Trap material for studies on response to hue was purchased from GE polymershapes, Phoenix, AZ. Trap colors were white, yellow, orange, red, blue, purple, green, clear and black, and all colors were translucent (reflectance spectra; red, green, blue [RGB] and hue, saturation and luminosity [HSL] values of these colors are provided below). They were fabricated from 0.02-mm-thick rigid vinyl plastic sheeting and were cut into 60×30 cm rectangles. One additional color, opaque yellow, was cut from high-density plastic sheeting (Cat. no. 01-4000-1; Hummert International, Earth City, MO). This is a standard yellow sticky trap color used in greenhouse monitoring of whiteflies and aphids (Muirhead-Thomson, 1991). For all colors, a 1-cm-diameter hole was punched into each of the four corners of the 60×30 cm rectangles using a Rotex punch press (Rotex Punch Co., Inc., San Leandro, CA). Traps were then hand rolled on one side with a thick coating of Pestick adhesive (Hummert International, Earth City, MO).

To hang traps, lath screws (8×1) with 1-cm-diameter heads were screwed into wooden laths (120 cm tall). The top screw was placed 11 cm from the top of the lath and the bottom screw was placed 25 cm below the top screw. The lath was then pounded into the ground and a sticky trap was placed onto the screws and wrapped around the lath to form an 18-cm-diameter cylinder, with its bottom and top $\sim$50 and 80 cm above the ground, respectively. At this height, the trap bottoms were always at or slightly above canopy height in alfalfa. In all trials, traps were placed 10 m apart.

Traps for studies on value (or intensity) used 0.03-mm-thick Kydex thermoplastic sheeting (Kleerdex Co., Reno, NV). Trap values were determined by matching trap color to the Liquitex value finder, which is based on Munsell value standards (Anonymous, 2001). Trap colors were polar white (#62000) with a value of 9, pewter gray (#52001) with a value of 6, dark gray (#52002) with a value of 4 and black (#52114) with a value of 1. Plastic sheeting was cut into 60×30 cm rectangles and treated as described above.

2.2. Measurement of color attributes

Reflected light and RGB values of the colored traps (with and without Pestick) used in these experiments were measured in the field between 1030 and 1200 h under sunny conditions (~100,000 lx) on 31 October 2005. Reflectance spectra were measured by a USB2000 spectroradiometer using OOIBase32 version 2.0.2.2 software (Ocean Optics Inc., Dunedin, FL). A solarization-resistant, UV-transparent, optical fiber (400 μm) probe with an adjustable collimating lens was held perpendicular to the trap surface to capture the spectral reflection. Reflectance intensity readings from the near UV through the visible wavelengths (300–850 nm) were automatically scanned using an integration time of 4 ms. Spectroradiometers are commonly used to record the wavelengths in a spectrum of light reflected from an object. However, there are some drawbacks to their use (Byers, 2006a). An inexpensive and readily available alternate method that can be used to describe color attributes objectively and quantitatively involves the use of a digital camera where pixels make up the images, and the pixels are colored based on an RGB system. Each pixel combines the three components in ranges from 0 to 255 in intensity. Any shade or color can be reproduced reliably with the RGB system, which is the most common color system used by computers. To determine the RGB values, the sticky-coated traps were photographed in the field using a Nikon Coolpix 2100 digital camera at the macro setting and at 1600 × 1200 pixel resolution. The resulting JPEG images were analyzed for color with the software described in Byers (2006a). RGB values were also converted to HSL values with Internet software.

2.3. Visual preferences of Lygus spp., key phytophages and predators relative to hue and value

Field trials were conducted between 2004 and 2006 in commercial alfalfa fields located on the University of Arizona, Maricopa Agricultural Center in Maricopa, AZ. Prior to all trials, four sets of 25 sweeps using a 38-cm diameter by 84-cm heavy duty sweep net (7212CM BioQuip Products, Inc., Gardena, CA) were made to determine species composition, density and sex ratios of resident *Lygus* spp. Females from the sweeps were dissected to determine reproductive status by counting the number of mature eggs, and mating status by counting the number of spermatophores in the seminal depository (Blackmer et al., 2004b; Villavaso, 2007).

In the autumn of 2004, on 28 September and 4 October, the preferences of *Lygus* spp., and other key herbivores and predators to hue (white, clear, black, yellow, orange, blue, purple, green and red) were examined using a randomized complete block design (RCB; $N = 4$). Traps were left in the field for 24 h and then returned to the laboratory, where lygus bugs were identified, counted and sex determined. Other key phytophagous insects that are sometimes damaging, *Colias* spp. (Lepidoptera: Pieridae), *Conotelus mexicanus* Murray (Coleoptera: Nitidulidae), *Spissistilus festinus* (Say) (Homoptera: Membracidae), *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) and *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) as well as the predators *Hippodamia* spp. (Coleoptera: Coccinellidae) and *Chrysoperla carnea* (Stephans) (Neuroptera: Chrysopidae), were counted and identified to species when possible. Because numbers were exceptionally high for *B. tabaci* and *F. occidentalis*, we estimated their numbers by counting the number found on three randomly selected, 4-cm^2 sections of each trap. These values were averaged and then multiplied by 112.5 (trap area/sample area or 1800/16 cm^2) to arrive at the total per trap.

In the spring and summer of 2005, the same colors plus opaque yellow (in August only) were tested. Traps were left up for 1 (24 May), 7 (12–18 August) or 14 days (12–25 August) depending on the experiment. In all trials, *Lygus* spp. and *Colias* spp. were counted and removed from the traps daily; *Colias* spp. quickly obscured the surface of the trap if left in place. The other phytophagous insects and predators were recorded at the end of the trapping period. Additionally, from 11 to 18 August in 2005, we conducted separate trials to examine insect response to trap value or intensity using black, white and two neutral grays as described above (RBC; $N = 4$). *Colias* spp. were counted and removed daily and the remaining phytophagous and predatory insects were counted at the end of the trial.

2.4. Effect of time of day

Time of day effect on the number of *Lygus* spp. captured was determined using sticky traps placed on 120-cm-tall laths (RCB; $N = 4$). Traps were monitored over two 24-h periods beginning at 09:00 h on 29 September and 5 October 2004. Counts were made at time intervals representing early morning (07:00–11:00 h—sunrise at 06:25 h), midday (11:00–15:00 h), dusk (15:00–19:00 h—sunset at 18:10 h) and overnight (19:00–07:00 h).

2.5. Effect of trap placement

To determine whether trap placement influenced trap catch, clear sticky traps were placed on 120-cm laths along the outside edge of an 8 ha alfalfa field, in the center of the field, or in a cleared buffer zone (2 m wide) between two 8 ha alfalfa fields. Eight traps were placed at each location, and at the end of 5 days (22–27 June 2006) traps were covered with wax paper and returned to the laboratory, where *Lygus* spp. were identified, counted and sex determined.

2.6. Trap height effect

Trap height effect was examined over a 5-day period (25–30 July 2006) using wooden stakes that were 90, 120, and 180 cm tall (RCB; $N = 6$ for each trap height). The trap bottoms were located ~20, 50 and 100 cm above the ground, which corresponded to within canopy, at canopy and above canopy levels in alfalfa. Clear traps were used for this study and were placed in a buffer area (2 m wide), consisting of bare ground, between two 8 ha alfalfa fields. One field was flowering and the other field was in a vegetative state. After 5 days, traps were covered with wax paper and returned to the laboratory for processing. *Lygus* spp. from the traps and sweeps were identified, counted and sex determined.

2.7. Effect of daily vs. weekly collections

Trapped *Lygus* spp. could potentially release defensive chemicals as well as sex, aggregation or alarm pheromones, and these compounds could influence subsequent trap catch. For this experiment, clear sticky traps were placed on 120-cm-tall laths ($N = 12$) that were left up for a 5-day period beginning on 25 July 2006. *Lygus* spp. were removed on a daily basis for one-half of the traps, while on the remaining traps lygus bugs were counted at the end of the 5-day period.

2.8. Statistical analysis

For experiments on visual preferences in 2004, sampling dates (28 September and 4 October) were analyzed by a three-way analysis of variance (ANOVA) using SigmaStat Software (version 2.0). In 2005, spring and summer counts for hue and value experiments for *Lygus* spp., other herbivores and predators were analyzed separately by two-way ANOVA. For time of day effect, trap counts were nearly identical for 29 September and 5 October, so they were combined for analysis. Counts were adjusted to reflect the longer sampling interval overnight, and then analyzed by two-way ANOVA. For trap placement and trap height effect, *L. hesperus* and *L. lineolaris* were analyzed separately by two-way ANOVA. Counts were transformed by $\sqrt{(y+0.5)}$ or $\ln(y+0.5)$ when needed to meet the assumptions of normality and homogeneity of variance. When data could not be normalized with these transformations, data were ranked and then analyzed by ANOVA (Conover and Iman, 1981; Payton et al., 2006). When F-statistics were significant, means were separated by Tukey tests. To determine whether trap captures were affected by previous collections of lygus bugs, cumulative trap catches for daily vs. weekly counts were compared for male and female *L. hesperus* and *L. lineolaris* by t-tests.

3. Results

3.1. Trap reflectance intensity, RGB and HSL values

Intensity counts relative to wavelength (nm) are represented for each trap color in Fig. 1. The black trap had very-low-intensity counts across all wavelengths measured. The remaining colored traps had complex intensity–wavelength curves relative to one another. Green had a dominant peak in intensity from 490 to 525 nm, and a second much smaller peak at approximately 410 nm, and red had a dominant peak from 595 to 635 nm, with a smaller peak from 490 to 550 nm (Fig. 1A). The blue traps increased in intensity above 395 nm, culminating at 495 nm before decreasing, purple had two peaks of lower intensity, one at about 490–515 nm and another at 580–610 nm, while orange also had two peaks, one at 475–540 nm and a second somewhat larger peak at 575–625 nm (Fig. 1B). White traps were of higher intensity and similar to blue from 400 to 500 nm (broad peak at 490–540 nm) and then gradually decreased in intensity similar to opaque yellow that had a peak at 530–570 nm, while translucent yellow was lower in intensity with a peak from 495 to 540 nm (Fig. 1C). The clear traps reflected less light than white, but in a similar pattern with most reflectance from about 485 to 535 nm; however, clear traps reflected more than white between 330 and 417 nm in the near-UV range (Fig. 1D). Pestick adhesive had virtually no effect on reflected spectra since the spectrograms of each color with or without adhesive were similar (data not shown). RGB and HSL values corresponded well with spectral data (Table 1).

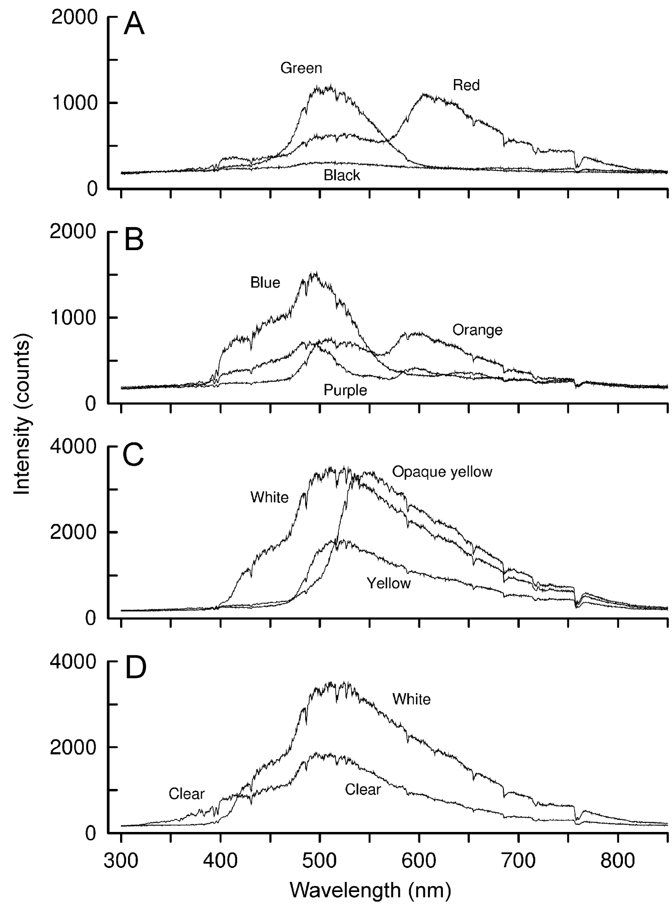

Fig. 1. Spectrograms of sunlight reflected from sticky traps of various hues: (A) black, green and red spectrograms, (B) blue, orange and purple spectrograms, (C) white, opaque yellow and translucent yellow spectrograms and (D) white and clear spectrograms. Reflectance measurements were taken in an alfalfa field with a USB2000 spectroradiometer at approximately midday, under clear skies in Maricopa, AZ.

3.2. Visual preferences of Lygus spp., key phytophages and predators relative to hue

In late September to early October 2004, the majority of lygus bugs in sweeps were *L. hesperus* (97.1%). There was an average of 0.75 ± 0.25 (mean $\pm$ SEM) individuals per

Table 1
Mean (±SEM) red (R), green (G), blue (B), trichromatic percentages (R, G, B%), and hue (H), saturation (S) and luminosity (L) values from areas of digital photos of colored sticky traps taken under field conditions on 31 October 2005

Trap color	R±SEM	R%[a]	G±SEM	G%	B±SEM	B%	H:S:L
Yellow	182±18	38.9	199±16	42.5	87±19	18.6	46:120:135
Opaque yellow	216±15	46.1	200±19	42.6	53±16	11.3	36:162:127
Orange	223±10	54.3	130±12	31.6	58±12	14.1	17:173:132
Green	53±13	14.4	192±14	52.0	124±17	33.6	100:136:115
Purple	135±16	33.7	101±15	25.2	165±17	41.2	181:63:125
Blue	84±14	18.8	163±15	36.4	201±16	44.9	133:125:134
Red	236±7	67.2	58±10	16.5	57±11	16.2	0:198:138
Clear	141±20	32.0	161±19	36.6	138±26	31.4	75:26:141
Black	61±13	32.4	65±13	34.6	62±12	33.0	90:8:59
White	209±13	33.2	212±12	33.7	208±12	33.1	70:11:198

Areas analyzed in pixels ($N = 1216$) and by Java software from Byers (2006a).
[a]Represents percent red (R/(R+G+B) × 100); G% and B% are defined similarly.

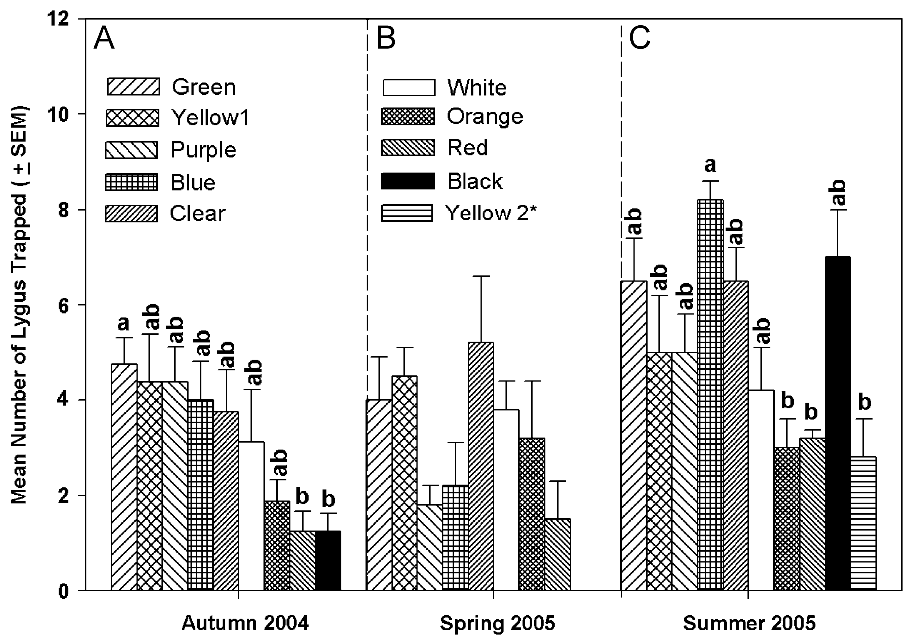

Fig. 2. Mean number (±SEM) of *Lygus* spp. trapped on sticky traps of various hues in alfalfa in the (A) autumn of 2004, (B) spring of 2005 and (C) summer of 2005. Means followed by the same lowercase letter are not significantly different (Tukey test at $P \leq 0.05$). *Yellow 2 = opaque yellow was used only in the summer of 2005.

sweep and a sex ratio of 2.1:1.0 (male:female). Approximately 57% of the females had eggs, with an average of 8.9±1.7 eggs. Forty-seven percent of the females had one or more spermatophore. Trap hue played a significant role in trap catch (Fig. 2A; $F = 3.90$; df = 8, 71; $P = 0.004$). More *Lygus* spp. were trapped on green than on red and black traps, but other trap hues were not significantly different from one another (Fig. 2A). All other phytophagous insects trapped showed distinct trap hue and sometimes value preferences. *Colias* spp. preferred translucent yellow over all other colors (Fig. 3A; $F = 16.80$; df = 8, 71; $P < 0.001$). *C. mexicanus* showed a strong preference to white that was significantly different from all other colors (Fig. 3A; $F = 104.60$; df = 8, 71; $P < 0.001$). *S. festinus* demonstrated a preference for translucent yellow that was different from all other colors except orange and green (Fig. 3A; $F = 8.32$; df = 8, 71; $P < 0.001$). *B. tabaci* also showed a strong response to translucent yellow over all other colors (Fig. 3A; $F = 71.19$; df = 8, 71; $P < 0.001$). *F. occidentalis* demonstrated a distinct preference for white and blue over all other colors (Fig. 3A; $F = 20.58$; df = 8, 71; $P < 0.001$). Very few predators were trapped, but *Hippodamia* spp. preferred translucent yellow, orange and white traps over red and black traps (Fig. 4A; $F = 5.15$; df = 8, 71; $P < 0.001$) and *C. carnea* showed a preference for red traps over clear and black traps (Fig. 4A; $F = 4.74$; df = 8, 71; $P = 0.001$).

In late May of 2005, the majority of lygus bugs in sweeps were again *L. hesperus* (96.2%). There were 2.91±0.36 individuals per sweep and the sex ratio was 1.0:1.0. Females had on average 7.82±0.55 eggs and approximately 84% had eggs. Seventy-eight percent of the females

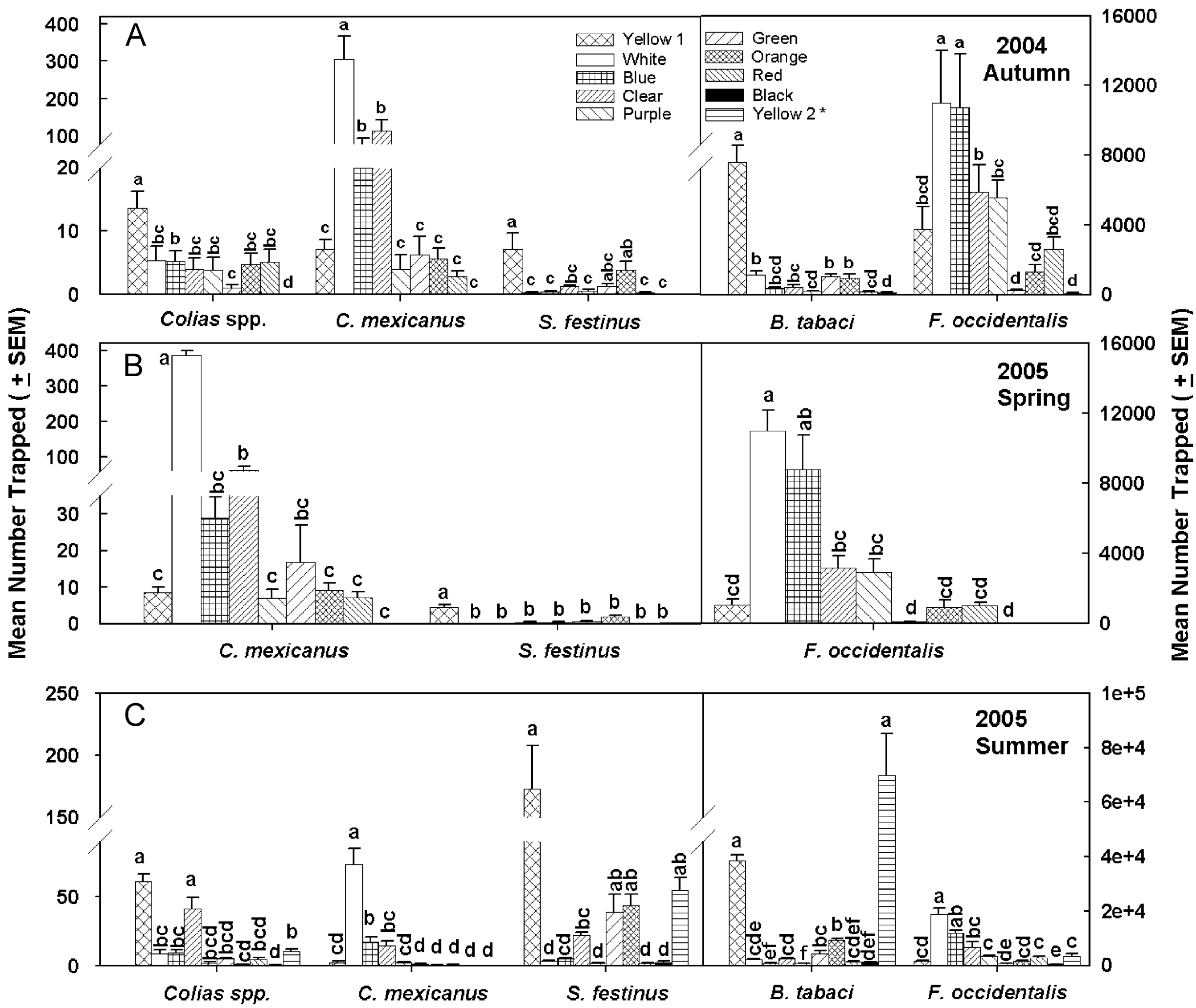

Fig. 3. Mean number (±SEM) of *Colias* spp., *C. mexicanus*, *S. festinus*, *B. tabaci* and *F. occidentalis* trapped on sticky traps of various hues in alfalfa in the (A) autumn of 2004, (B) spring of 2005 and (C) summer of 2005. Means followed by the same lowercase letter are not significantly different (Tukey test at $P \leqslant 0.05$). *Yellow 2 = opaque yellow was used only in the summer of 2005.

had one or more spermatophore. Trap hue did not significantly affect *Lygus* spp. trap catches in the spring of 2005 (Fig. 2B; $P = 0.07$). Trap catches for *Colias* spp., *B. tabaci* and *C. quadrimaculatus* were too low for analyses in May; however, *C. mexicanus* showed a strong preference to white that was significantly different from all other colors (Fig. 3B; $F = 149.4$; df = 8, 35; $P < 0.001$). *S. festinus* demonstrated a distinct preference for translucent yellow that was different from all other colors ($F = 11.51$; df = 8, 35; $P < 0.001$). *F. occidentalis* demonstrated a distinct preference for white over all colors except blue, and blue was preferred over all colors except purple and clear (Fig. 3B; $F = 17.62$; df = 8, 35; $P < 0.001$). For predators, *Hippodamia* spp. were trapped more frequently on orange than on all colors except translucent yellow, green and clear (Fig. 4B; $F = 14.08$; df = 8, 35; $P < 0.001$). *C. carnea* was trapped more frequently on clear than on all other colors (Fig. 4B; $F = 11.27$; df = 8, 35; $P < 0.001$).

On 12 August 2005, the majority of lygus bugs in sweeps were *L. hesperus* (86.8%). There were 0.38 ± 0.02 individuals per sweep and the sex ratio was 1.5:1.0. Females had on average 10.5 ± 1.7 eggs and approximately 93% had eggs. Sixty-four percent of the females had one or more spermatophore. The 7-day trap catches did not show a significant difference relative to trap catch (data not shown, $P = 0.34$); however, there were significant preferences demonstrated in the 14-day collections (Fig. 2C; $F = 4.41$; df = 9, 39; $P < 0.001$). Blue was preferred over orange, red and opaque yellow. *Colias* spp. showed a strong preference for translucent yellow that was different from all other colors except clear, and clear was preferred over all remaining colors (Fig. 3C; $F = 30.01$; df = 9, 39; $P < 0.001$). *C. mexicanus* showed a strong preference for white that was significantly different from all other colors (Fig. 3C; $F = 23.13$; df = 9, 39; $P < 0.001$). *S. festinus* demonstrated a distinct preference for translucent yellow that was different from their response to most other colors

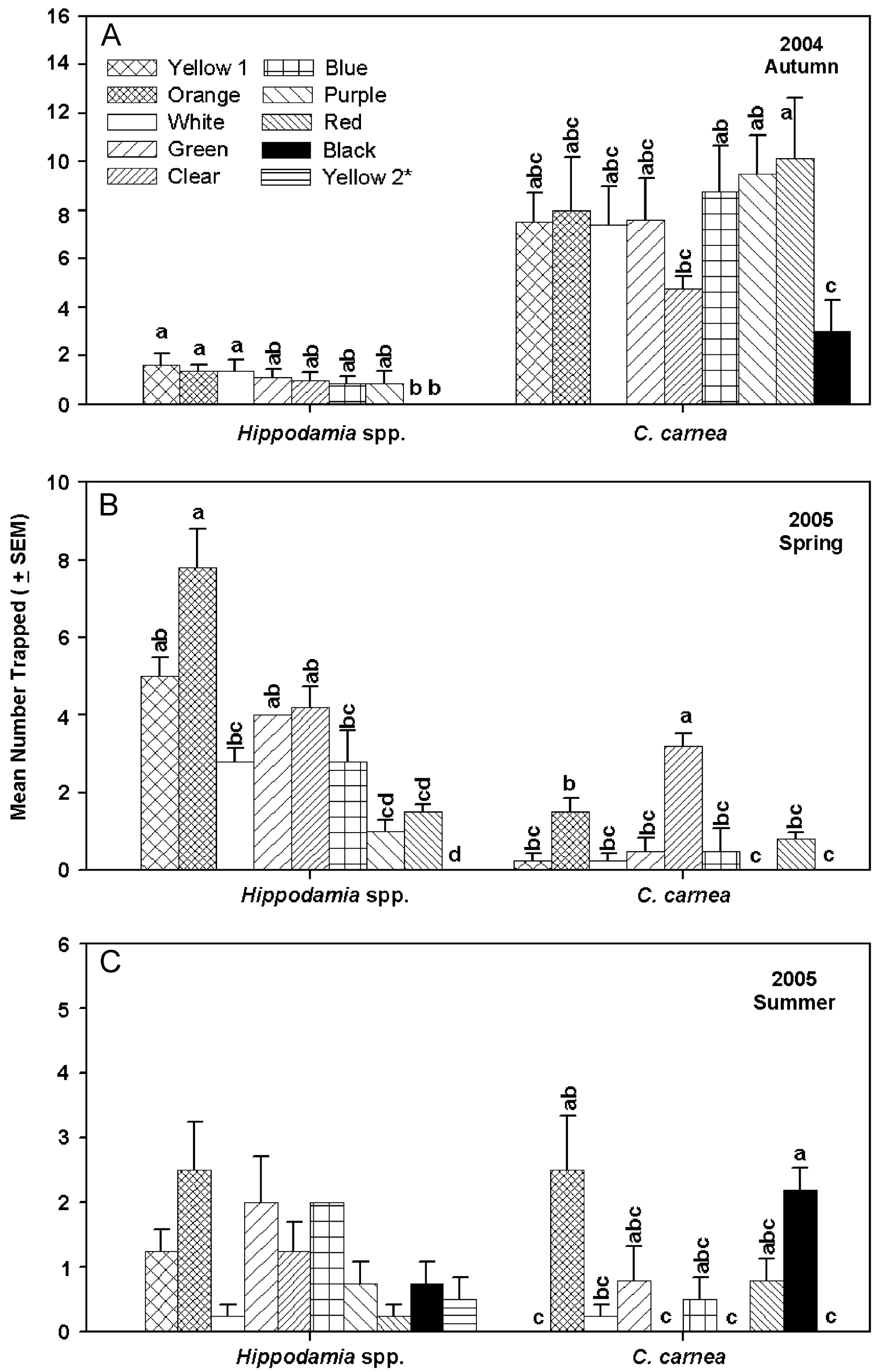

Fig. 4. Mean number (±SEM) of *Hippodamia* spp. and *C. carnea* trapped on sticky traps of various hues in alfalfa in the (A) autumn of 2004, (B) spring of 2005 and (C) summer of 2005. Means followed by the same lowercase letter are not significantly different (Tukey test at $P \leqslant 0.05$). *Yellow 2 = opaque yellow was used only in the summer of 2005.

(Fig. 3C; $F = 26.59$; df $= 9, 39$; $P < 0.001$). *B. tabaci* showed a strong response to opaque yellow over all other colors except translucent yellow (Fig. 3C; $F = 56.95$; df $= 9, 39$; $P < 0.001$). *F. occidentalis* demonstrated a distinct preference for white over all colors except blue, and blue was preferred over all colors except clear (Fig. 3C; $F = 22.96$; df $= 9, 39$; $P < 0.001$). For predators, *Hippodamia* spp. showed no significant preference among colors ($P = 0.12$). *C. carnea* preferred black and orange over most other colors (Fig. 4C; $F = 5.78$; df $= 9, 39$; $P = 0.001$).

3.3. Visual preferences of Lygus spp., key phytophages and predators relative to value

Lygus spp. showed no preference relative to trap value (Fig. 5; $P = 0.86$). *Colias* spp. demonstrated a strong

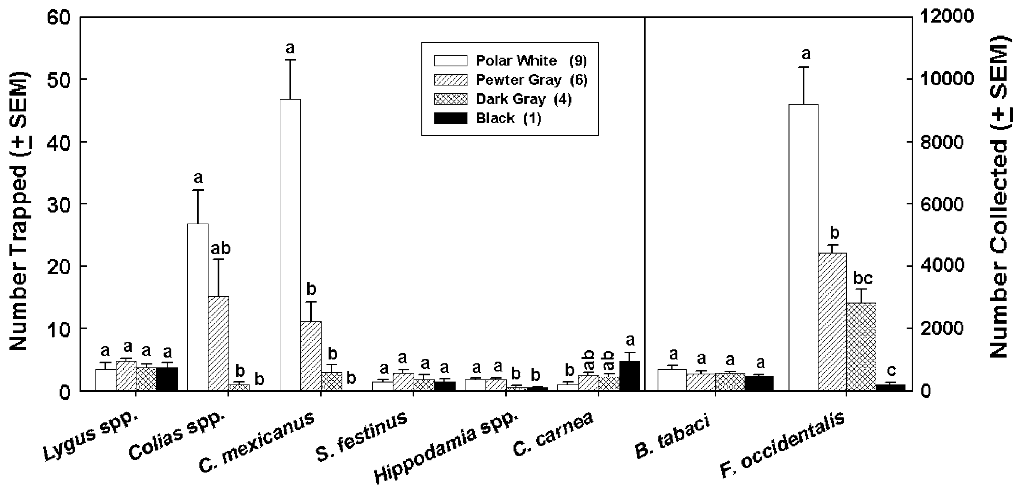

Fig. 5. Mean number trapped (±SEM) of *Lygus* spp., *Colias* spp., *C. mexicanus*, *S. festinus*, *Hippodamia* spp., *C. carnea*, *B. tabaci* and *F. occidentalis* relative to value (1, 4, 6, 9). Means followed by the same lowercase letter are not significantly different (Tukey test at $P \leqslant 0.05$).

preference for high-value traps; white was preferred over black and dark gray, but not pewter gray ($F = 5.44$; df $= 3, 15$; $P = 0.02$). *C. mexicanus* also demonstrated a strong preference for white over all other traps (Fig. 5; $F = 24.24$; df $= 3, 15$; $P < 0.001$). The two homopteran species, *S. festinus* and *B. tabaci*, did not demonstrate a preference relative to value ($P = 0.68$ and 0.67, respectively). *F. occidentalis* demonstrated a distinct preference for white over all colors, and pewter gray was preferred over black ($F = 22.46$; df $= 3, 15$; $P < 0.001$). For predators, *Hippodamia* spp. showed a slight preference for high-value traps, with white and pewter gray being preferred over black and dark gray ($F = 4.41$; df $= 3, 15$; $P = 0.04$). *C. carnea* was trapped more frequently on low-value traps, with black preferred over white traps ($F = 4.13$; df $= 3, 15$; $P = 0.04$).

3.4. Effect of time of day

Although *Lygus* spp. were caught in small numbers throughout the day and night, time of day had a significant effect on trap catch (Fig. 6; $F = 30.53$; df $= 3, 31$; $P < 0.001$). Approximately 50% of the trapped individuals were caught in the 4-h interval between late afternoon and dusk (15:00–19:00 h).

3.5. Effect of trap placement

During this trial, sex ratios of trapped individuals were male biased, with *L. hesperus* at 10:1 and *L. lineolaris* at 8.3:1. Sweeps prior to and following the trial indicated that the sex ratio in the field was ~1:1, so males were either more attracted to the traps or were much more active fliers at this time of the year than females. All females, both pre- and post-trial, had mature, fully chorionated eggs, with a mean of 13.1 ± 0.77 eggs, and 66% had one or more spermatophores. Of the individuals trapped, 76% were *L. hesperus* and both males and females of this species were

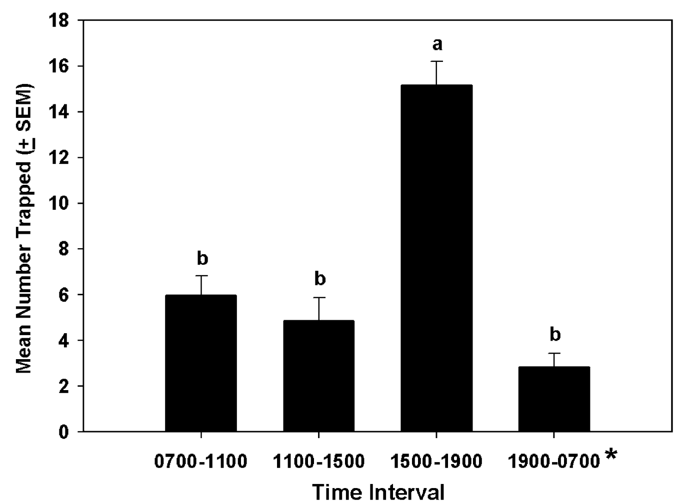

Fig. 6. Mean number (±SEM) of *Lygus* spp. trapped on sticky traps in alfalfa relative to the time of day during two 24-h collections on 29 September and 5 October 2004. Means followed by the same lowercase letter are not significantly different (Tukey test at $P \leqslant 0.05$). *Normalized to a 4-h interval.

influenced by the location of the trap. Significantly more individuals were captured when traps were placed between the two 8-ha alfalfa fields ($F = 5.11$; df $= 2, 23$; $P = 0.02$ for females and $F = 47.04$; df $= 2, 23$; $P < 0.001$ for males) than when placed in the center or at the outside edge of the alfalfa field. Very few *L. lineolaris* females were trapped and differences in capture relative to placement were not detected ($P = 0.33$); however, male *L. lineolaris* were caught more frequently on traps placed between the two alfalfa fields ($F = 4.98$; df $= 2, 23$; $P = 0.02$) than on traps placed on the outside edge of the alfalfa field.

3.6. Trap height effect

At the time of these collections in late July, the number of *Lygus* spp. per sweep averaged 0.72 ± 0.18 in the flowering alfalfa and 0.57 ± 0.10 in the vegetative alfalfa. The sex ratio was 1.6:1.0 in the flowering alfalfa and 1.0:1.0 in the vegetative alfalfa. Approximately 75% of the females in flowering alfalfa had eggs with a mean of 10.0 ± 0.36 and 46% had at least one spermatophore. In vegetative alfalfa, 97% of the females had eggs with a mean of 11.4 ± 0.46 and 66% had at least one spermatophore. On the traps, the sex ratio was 2.4:1.0, indicating that males were more likely than females to be trapped; however, sex ratio varied considerably with height. At mid-canopy (90-cm stakes) the sex ratio was 3.5:1.0, while at canopy (120-cm stakes) and above canopy (180-cm stakes) the sex ratio was 1.0:1.0. *L. hesperus* accounted for 72.6% of the collection; most of the remainder were *L. lineolaris*. For *L. hesperus*, more individuals were trapped on 90-cm stakes than on the 120- and 180-cm stakes ($F = 24.32$; df $= 2, 35$; $P < 0.001$), and, regardless of height, more males than females were trapped ($F = 15.62$; df $= 1, 35$; $P = 0.003$). For *L. lineolaris*, more individuals were trapped on the 90-cm stakes than on the 180-cm stakes ($F = 8.56$; df $= 2, 35$; $P < 0.007$), but 90- and 120-cm stakes caught similar numbers. There was no significant difference in trap catch for male and female *L. lineolaris* ($P = 0.27$).

3.7. Effect of daily vs. weekly collections

Similar numbers of *Lygus* spp. were trapped regardless of whether they were removed on a daily basis for 5 days, and then totaled or counted at the end of the 5-day period ($t = 1.0$; df $= 46$; $P = 0.32$). The response was similar for female *L. hesperus* ($t = 1.26$; df $= 10$; $P = 0.24$) and *L. lineolaris* ($t = 1.52$; df $= 10$; $P = 0.16$), as well as for male *L. hesperus* ($t = -0.05$; df $= 10$; $P = 0.96$) and *L. lineolaris* ($t = 0.34$; df $= 10$; $P = 0.74$).

4. Discussion

Many phytophagous insects respond positively to light reflectance patterns of their host plant, and these responses can be quite specific. Very often, substrates that reflect maximally between 500 and 580 nm elicit the greatest response; however, in some cases, the response may be associated with a particular stage of the host plant (e.g., flowering or fruiting stage) where reflectance is maximal in other regions of the spectrum (Prokopy and Owens, 1983). Knowledge of these behaviors has allowed us to effectively monitor many economically important pests. Here we examined the response of several key alfalfa herbivores and predators to trap hue and value. Particular emphasis was placed on the response of the generalist herbivore, *L. hesperus*, which has become one of the most important pests in the Southwest in recent years. *L. hesperus* made up a large percentage (>85%) of all lygus bugs collected, and, in general, their response to trap hue was broad and not very discriminating; however, over the three seasons, the top four hues in terms of numbers trapped were green, blue, clear and translucent yellow. Although males were trapped more frequently, no gender-related differences in response to trap hue were detected. Male biases on sticky traps, despite 1:1 ratios in the field, have been reported previously for *L. lineolaris* (Prokopy et al., 1979; Boivin et al., 1982; Boivin and Stewart, 1984). Male trap catch biases for *L. hesperus* have not been reported previously, but our findings, together with previous findings for *L. lineolaris*, suggest that males are either more active fliers or more attracted to sticky traps than females. This latter alternative is less likely. Prokopy et al. (1979) found no differences in preferences by male and female *L. lineolaris* among the various hues tested, and neither did we for *L. hesperus* (J.L.B., unpublished data). Given the high percentage of females with eggs over all three seasons, it seems likely that they were trapped less frequently because they were engaged in egg-laying behavior. In previous studies, we found no evidence that having mature eggs negatively affected their ability to fly (Blackmer et al., 2004b), although this needs to be examined more closely in the field. In terms of trap value or intensity, *Lygus* spp. exhibited no preference; high-intensity traps (white) caught as many lygus bugs as low-intensity (black) traps.

In contrast, all other insect species monitored during these studies demonstrated distinct preferences to trap hue and, in some cases, to trap value. Neither of the homopteran species, *S. festinus* and *B. tabaci*, responded to trap value, but did show a strong response to yellow hues. Todd et al. (1990) obtained similar responses with the leafhoppers, *Dalbulus maidis* (DeLong and Wolcott), *Dalbulus gelbus* DeLong and *Dalbulus quinquenotatus* DeLong and Nault, which responded strongly to yellow, but not to neutral grays, indicating that their responses were primarily due to hue and not value.

Colias spp., *C. mexicanus* and *F. occidentalis* all showed a strong response to high-value traps, but their response to hue differed. *Colias* spp. responded strongly to translucent yellow, whereas *C. mexicanus* and *F. occidentalis* both responded strongly to white, blue and clear traps. Several researchers have reported that blue or white traps are attractive to *F. occidentalis* (Yudin et al., 1987; Vernon and Gillespie, 1990; Matteson and Terry, 1992; Roditakis et al., 2001), while Chen et al. (2004) reported a stronger attraction to blue or yellow traps than to white traps. Direct comparisons between studies are difficult, however, because trap hue, design and deployment varied among studies. No other studies have examined the response of *Colias* spp. or *C. mexicanus* to visual cues, but in both cases, as well as for *F. occidentalis*, these insects were responding to both hue and value.

Few predators were trapped during our studies, but *Hippodamia* spp. did show a preference for translucent yellow and orange traps and responded to traps of higher value. *C. carnea,* on the other hand, preferred low-value traps and had a variable seasonal response to orange, red, black and clear hues. Maredia et al. (1992) obtained similar responses to trap hue (red, orange, black, white, blue, yellow and green tested) by two predators. Although numbers were low, they found that *Coccinella septempunctata* (L.) consistently responded to yellow traps regardless of location. *C. carnea* also responded to yellow, but green, red, black and orange traps captured similar numbers depending on the location. In trapping *Lygus* spp., inadvertent trapping of beneficial predators could be reduced by utilizing green, blue or clear sticky traps.

In addition to testing response to trap visual cues, we examined the effect of time of day, trap height, trap placement, and whether insect-associated pheromones or defensive compounds might influence the subsequent trap catch of *Lygus* spp. Most lygus bugs were trapped between late afternoon and sunset in alfalfa. Mueller and Stern (1973) also found that *L. hesperus* was most active at dusk. Butler (1972) reported that *L. hesperus* actively engaged in flights 1 h before sunrise and 1 h after sunset; however, this study only covered a 3-day period during the summer and all collections were made between 1 and 3 m above ground. *L. lineolaris* was reported to be most active at midday (Rancourt et al., 2000). In our studies, the number of *L. lineolaris* captured was too low to accurately determine the time of day effect. The other three parameters measured (trap height, trap placement and effect of pheromones) have not been examined for *L. hesperus*. However, for *L. lineolaris*, several researchers reported that, similar to our findings, most individuals were trapped less than 1 m above the ground (Prokopy et al., 1979; Boivin and Stewart, 1984; Rancourt et al., 2000). For several insect species, host plants surrounded by bare ground are more often visually apparent and consequently these plants receive more visits (Smith, 1976; Rausher, 1981). These findings support our results that trap placement over bare ground between two alfalfa fields trapped more *Lygus* spp. than traps placed in the center or at the edge of the field. For presumed pheromones (aggregation, alarm and/or sex) or defensive volatiles (Byers, 2006b), we found no evidence that trapped *Lygus* spp. released any chemicals that influenced subsequent trap collections.

In conclusion, *Lygus* spp. exhibited a broad response to hue, as predicted for a generalist herbivore (Prokopy et al., 1982; Prokopy and Owens, 1983), and their response varied relative to trap placement, height and time of day. If the intent is to maximize *Lygus* spp. collections while minimizing beneficial predator capture, our trials suggest that green, blue or clear traps should be placed between alfalfa fields over bare ground, at less than 1 m high. Yellow traps have been used in the past, but over longer trapping periods we found that the preference for yellow by other herbivores (i.e., *S. festinus*, *B. tabaci* and *Colias* spp.) interfered with lygus bug captures (J.L.B., unpublished data). Despite the limitations that such sticky traps have (e.g., only measure adult activity, may not be indicative of damage in the field, and are subject to dust and debris requiring weekly changes), this information will be useful in monitoring adult *Lygus* spp. and may provide us with a relative measure of immigration into sensitive crops, as well as pest pressure among fields. Future studies will focus on enhancing male and female response to our sticky traps, and this will likely involve looking at the role of plant phenology, insect reproductive status and the interaction between visual and volatile plant cues, which we found to be important in the laboratory setting (Blackmer et al., 2004c; Blackmer and Cañas, 2005).

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